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## **A 3D City Model Used as User-interface for an Energy-System**

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**Abstract:** At CUPUM 2009 the project “Object Oriented Visualization of Urban Energy Consumption” was presented, explaining the technology behind the visualization of an energy-model connected to a 3D city model. This paper presents the subsequent work involving the final design, the user involvement and the overall results after the system has been used at the Bright Green Exhibition connected to the COP15 conference in Copenhagen.

This paper presents the empirical findings of the attempt to use a 3D city model as user-interface. The system gave the user the possibility to try out different scenarios of combinations of the energy-consumption and energy-production for an entire city. The interface was supposed to help especially nonprofessionals, among them politicians, to better perceive the numbers and graphs adjoining the 3D model in a combined view.

Only very few systems have been developed for this kind of interaction, why the design guide lines for this development was a mix of believe and trial and error. To minimize the developing time and induce a steeper learning curve, it was obvious to use similar techniques for the different inputs and controls. Though the energy model, behind the visualization, could handle a lot more input parameters, only 6 different but important ones where implemented and could be adjusted. The assumption was that the handling of too many parameters would confuse more then benefit the user.

**Keywords:** City, 3D, Visualization, User, Interface, Energy-model

## 1. INTRODUCTION

One of the biggest challenge each software design is facing, is the user interaction. A good interface is crucial to get people voluntarily to interact with a system or application (Bowman et al. 2001). Apple for instance has a huge success recently partly due to their very user-friendly design. The challenge is not only to make the interface logically and intuitively appealing but also to find the right compromise between the numbers of adjustable features and system flexibility faced to a clear and user-friendly environment. This challenge is even more demanding when the model scale is given by the extent of a whole country or “only” a city. Map makers and the GIS community have been working with this issue for decades but are quite often still lacking a good solution (Tomlin, 1990), (Takeyama & Couclelis, 1997), (Burrough, 2001). When it comes to 3D city models, it is very difficult to present information within a 3D environment due to the constructional details and textures one want to show on one hand and the information presented within the model on the other. But this is exactly what we had to do.

This paper is based on a project called EnergyCity developed by the Centre for 3D GeoInformation at Aalborg University. This project is situated in the city of Frederikshavn in the north part of Denmark. The goal for the project was to make a 3D city model act as an awareness tool allowing politicians as well as citizens to visualize and understand the change of energy consumption and energy sources in an urban environment over a period of time. The challenge here was not only to show geographic related information in a city scale but actually to convince the user to be aware of consequences due to the production and use of energy in a city context. This system was supposed to be used by all kinds of laymen like school children, politicians and common citizens. The idea was to give the user an immediate response to their action so that they could realize how the change of energy consumptions matters, which helps them to realize a more sustainable while feasible energy scenario. While the basic technological platform was presented at CUPUM in Hong Kong in 2009 (Kjems & Bodum, 2009) this paper has its focus on the user interaction and the experience we got due to a large number of presentations at the Bright Green Exhibition in Copenhagen, December 2009 where close to a 1000 people came to the booth wondering what we were showing.

## 2. THE BASIC INTERACTION

The application combines a 3D city model with a purely numerical based model named EnergyPLAN (Lund and Münster, 2003, Lund and Østergaard, 2008) and an object-oriented (OO) geo-visualization platform called GRIFIN (Bodum et al., 2005; Kjems et al., 2009). The view one is facing at startup is shown in Figure 1. The overall project EnergyCity is supposed to help users to understand the rather complex energy system dealing with a sustainable and feasible energy scenario on city level by allowing the interaction between users and a few selected dynamic features representing plausible energy sources and the energy consumption. For this purpose, the dynamic features in our project plays a significant role for bridging numerical calculations and 3D visualizations (Yuan, 2004). For example, when the users increase the population of wind turbines, more wind turbines are immediately shown in the 3D city model. Meanwhile, the changed parameters can be submitted to the underlying EnergyPLAN and the results are presented as graphs after a few seconds.

The application shown in Figure 1 consists of a city model view, a control panel (lower



Figure 1 This image shows the complete system with the 3D model in the upper part, the control panel in the lower left and the graphs on the lower right.

left) and a graphical part showing the energy consumption for a period of 4 days. So all important parts of the application were combined in one view. Moving the mouse over the model gave the possibility to navigate around the model while moving the mouse over the control panel was enabling people to change the slider positions.

The control panel had actually several actions which were timely separated. Altering the slider position immediately would effect changes in the model, but due to very demanding calculations in EnergyPLAN these changes would only effect changes in the graphs as well after clicking on the submit button. This quite often caused some confusion though people easily could understand the reason for that inexpediency.

The lower part of the control panel allows the user to interact with the graphs. Moving the two sliders gives one the possibility to see the energy consumption of a particular day of the year at a certain time of the day. Though since the graph window is covering 4 days along the axis the slider presenting 24 hours for one single day is rarely used. Finally there is a possibility to let the days pass by as a kind of animation, which primarily has a nice graphical effect but none really useful.

The application is handling two separate flows sharing the input from the control panel. Moving the sliders gives an expected immediate result in the 3D model while the calculation of the overall energy consumption awaits an active submission. Clicking on the green submit button will send the input from the control panel to the EnergyPLAN server which returns the result within about 10 seconds and the application will present it as graphs and

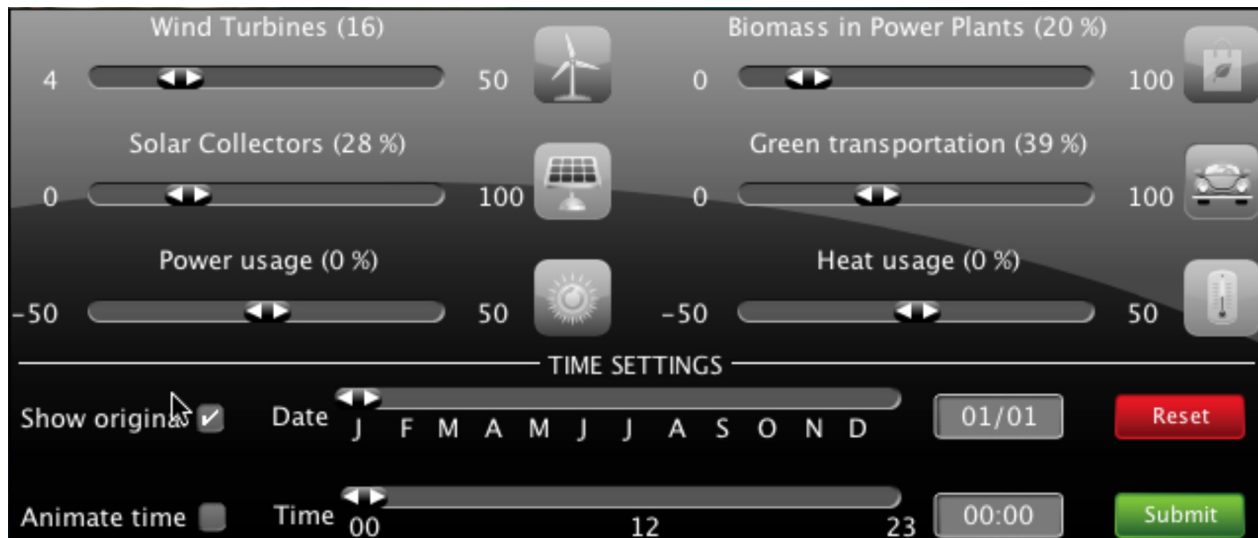


Figure 2 The Control Panel used to change the energy consumption and the change of energy production along with the time settings.

numbers.

### 3. THE CONTROL PANEL

The control panel shown in Figure 2 has 3 sliders controlling the energy production and 3 sliders controlling the energy consumption. Probably an improved visual differentiation in the control panel would make this more clear. The immediate changes in the model connected to the sliders are shown in three different ways. Adding or subtracting graphical elements like the wind turbines, changing colours of elements or changing the geometry of elements. To make the navigation easier and to show changes more obvious the model has predefined point of views for each slider action. For instance if you want to add wind turbines, the first touch on the slider will move the point of view into the sea giving an overview of the wind turbines that are added or removed. Moving the mouse at that point gives you the possibility to look in different directions but not to pan anywhere. Changing the energy production will give a view of most of the city scape, etc. By pressing the **esc** key the navigational constraint is released and one can move freely in the model.

#### 3.1. Wind Turbines

The change in numbers of wind turbines in the model were presented by showing the number of wind turbines appear and disappear in the city model according to the position of the slider and the number shown in the brackets, see Figure 3. The number of wind turbines is the one most significant factor for the power production why the graphs from the numerical calculation accordingly should change considerably. Due to the demanding calculation, as explained earlier, only a click on the submit button will change the graph though. Another feature implemented in the 3D model is the animation of the propeller. The speed of the propeller is changing along with the graph and the actual wind production at a specific day of the year and time of the day. During an animation sequence the speed will change a lot because the hourly production rate is shown in matters of a few seconds covering a whole day. The added wind turbines in the model will not have moving propellers right away. Only after the submission and a recalculation of the energy scenario the added wind turbines will have rotating propellers as well.



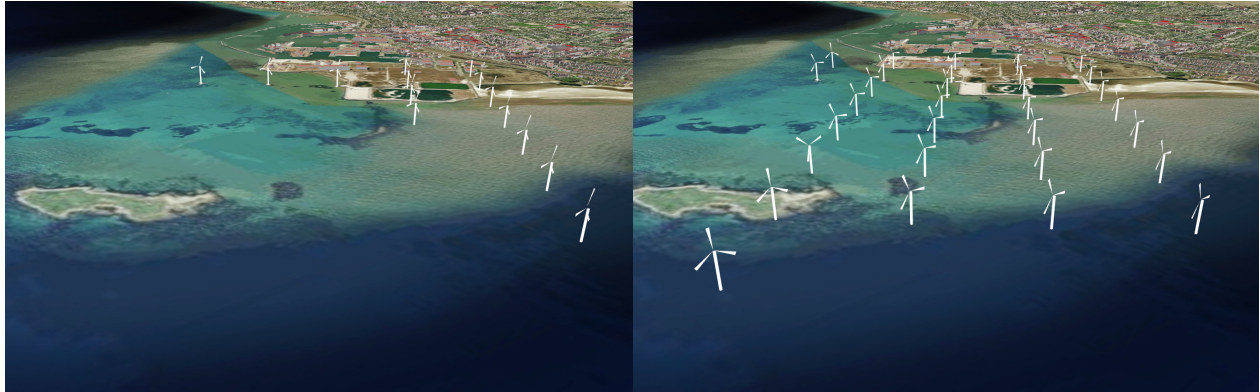


Figure 3 Change of wind turbine population

### 3.2. Biomass Production

The increase or decrease in the decomposition of biomass is presented quite similarly by showing a number of green silos appearing and disappearing according to the percentage of possible biomass use. The view presented is an almost close up to a sketched plant.

### 3.3. Solar Collectors

Solar collectors are only appearing on specific roof sites, see Figure 4. As a matter of limited resources and a fast approaching deadline the selection of potential roofs suitable for solar collectors were done rather pragmatic than correctly. The result showed a limited amount of the smaller buildings getting solar collectors attached according to the percentage settled by with the slider. The solar collectors are shown by changing the colour of the one roof site pointing primarily towards south as the most plausible choice of roof site. Actually the colour change was achieved by adding another roof plate with a black colour right above the original roof. Adding an object and handling it for instance with colour change is much easier than picking one face of an existing object and changing it. At the very beginning we chose 2m\*2m squares with silver colours, which is a close to real representation of solar collectors, standing for individual solar collector models. However, in this way users could not perceive any visual effect indicating the situation of the whole city,

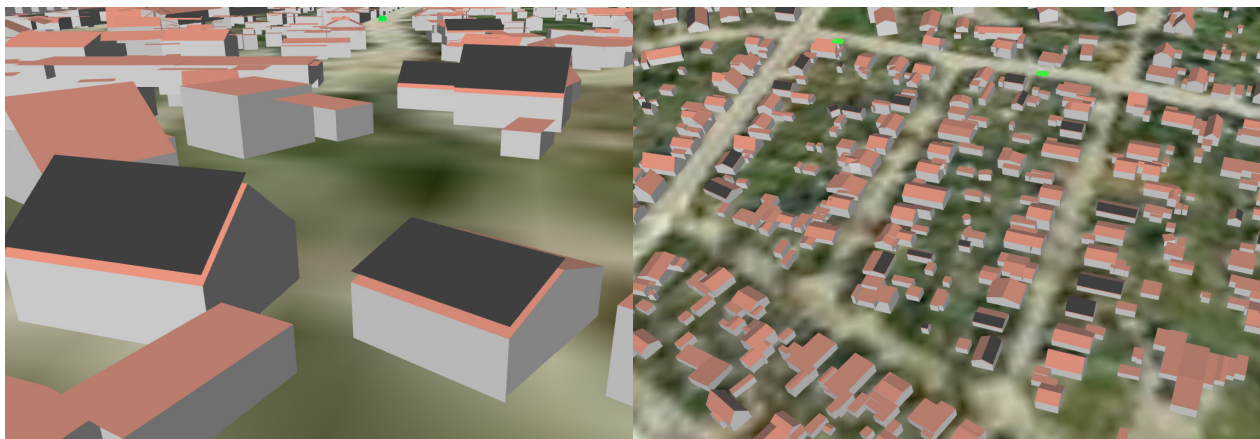


Figure 4 The amount of solar collectors appearing or disappearing on individual house roofs indicate the percentage of utilized solar energy in the whole city.



Figure 5 Changing the colour of the roofs in the model indicate the usage of electric power

because those realistic squares were visible only if zooming into individual buildings. At the end, we changed the geometry as big as the whole roof, and marked it with a noticeable dark colour, so that users can perceive a better impression of solar collectors placed on selected roofs when zooming out, see Figure 4 right hand side. If we could have spent more time on this single feature we would have developed better algorithms to detect more suitable roofs for placing solar collectors.

### 3.4. Green Transportation

From a visual perspective, the green transportation was presented similar though here simplistic and static cars in the model are set to change their colour going from white to green, indicating the shift to electric propulsion of all vehicles in the city. The colour change is achieved similar to the solar collectors though the white cars are simply replaced by green ones since the whole car is changing its colour. The share of green cars compared with white cars is presenting the share percentage chosen with the slider position. Originally we started out with very nice and different car models. We wanted them to move around in the city on certain paths simulating traffic but these approaches among other things turned out to be very CPU and GPU consuming why the idea was dropped.

### 3.5. Heat and Power Consumption

The consumption of electric power and heat, where the latter in most cities in Denmark is provided due to central heating, is presented as an all-over colour change of either the roof or the body of the buildings. For the case of the electric power the roofs will change from light green to dark red indicating a decrease or increase of power by 50%, see Figure 5; while the heat usage is shown with colour changes of the walls of the buildings going from deep blue to dark red indicating a decrease or increase ranging from -50% to +50% compared with actual usage of the heat to the start scenario. The reason why the colour change here is done differently is to the fact that the building objects are created and delivered as two coherent objects representing the roof and the building body respectively as two identifiable units. The price for the entire city model covering approximately 10.000 buildings with level1 (CityGML) details was close to \$13.000.



### 3.6. Landmarks

To make it easier for people to navigate around in the model-map and recognize parts of the city we decided to pick important buildings and make them appear with high details and preferable textured surfaces. Together with representatives from the municipality we sat down and pinpointed buildings in the model. But the peculiar thing was that while we, the developers, chose buildings which could help navigating around like high and voluminous buildings, the municipality chose buildings, which could be referred to due to important owners or buildings which were important to the municipality. If we chose one specific building ignorant to for instance the ownership we were told to pick another one as well which was identified as the business competitor despite that this building would be worthless from a navigational point of view. We ended up with a lot of buildings which were not really important for the navigation and the increased details turned out to be worthless as well because you need to stay quite close to notice the details. We had to skip the textured surfaces with for instance photographic images due to cost estimates. We chose to skip the building body and roof colouring of the landmark buildings to keep them easy identifiable, see Figure 5 left hand side. We would have done the same if photographic textures had been available.

### 3.7. Energy Consumption Graphs

The energy consumption graphs are showing the original scenario from 2008 in the left window and showing the modified scenario taking the new slider positions and thereby numerical inputs into account in the right window, see Figure 6. The EnergyPLAN model is developed specifically for the town of Frederikshavn based on records of the consumption and production of power and heat and also records of the wind speed from each and every hour in 2008, 8760 hours in all. The energy model uses a lot more input parameters but they are mostly estimated due to statistical measures.

For professionals the graphs say a whole lot more than simple changes in the 3D city model. Precise measures of CO<sub>2</sub> usage and comparable illustrations indicating for instance the importance of different choices of power and heat production which clearly show where to invest money and effort and where not.

## 4. THE BRIGHT GREEN EXHIBITION

The way the user or audience perceived the implemented interaction and the results shown by the city-model and the connecting graphs varied quite a lot. The system has

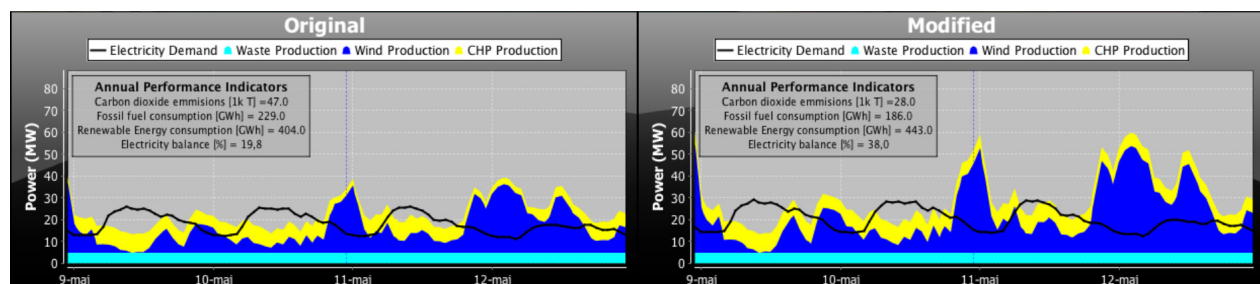


Figure 6 The energy graphs showing the energy production (coloured fields) and the consumption (black) line only for the power. The dark blue area for instance is showing the power production coming from wind turbines why it is changing a lot during the day.



been presented at the Bright Green Exhibition in Copenhagen in conjunction with the COP15 Climate Conference December 2009. The audience was spreading from school children to professionals within energy production, monitoring systems or consultancy. It was very clear and not unexpected that professionals were focusing on the graphs rather than on the model. The city model though caught the attention of people dropping by the booth unintentionally. Nonprofessionals were playing with the sliders but not really paying any attention to the serious background of the system and the underlying energy calculations. But the ones who were just a bit interested in understanding the overall energy model could easily understand the connection between model and graph. The focus then slowly shifted from the model to the graph where even small differences in for instance green transportation could be observed as an increasing or decreasing amount of CO<sub>2</sub> in the overall energy calculation. A wind turbine running faster or slower does not really indicate whether you produce enough wind power to balance the energy consumption to the green side. But a graph lying beneath or beyond a line showing exactly that is very clear. The city model could have had an indicator for this particular purpose but it would not have been easy to implement it for several reasons. First of all the situation changes constantly like the speed of the wind turbine, and consequently the image would start to flicker a lot. Secondly the colours would disturb the appearance of the model and would have made other colour indicators less usable.

If one should draw an objective conclusion of the effect of the city-model for the purpose of visualizing the energy consumption of a whole city, the right word would probably be “overkill” though a nice one. Originally the idea with the project was to be able to identify every household in the model and that way show the exact energy consumption of each building and household showing the inhabitants of the city whether their individual consumption lays within an expected range or if they for instance spent too much energy compared to others. Due to legal regulations this was not possible. But an assumption can be made, that the 3D city model would have had a much larger impact to the public users. A new project in Norway with the title InfraWorld investigates the possibility of monitoring an urban area with regards to energy consumption on house hold level. Nevertheless, the control panel has been discovered as a very nice interface for the EnergyPLAN application even though the EnergyCity application today primarily is used for educational purposes explaining the energy balance calculation for a whole city.

## 5. CONCLUSION

This project faced the challenges of presenting changes due to an interactive user interface and changes of the overall energy consumption of the city of Frederikshavn. Not having numbers on the level of each individual building but only for the entire city as one unit actually increased this challenge rather than simplifying it, because it is difficult to make people understand the changes in the energy consumption for a whole city by presenting a 3D model that consists of individual 3D buildings. This paper elaborates our solution and considerations of representing and visualizing semantic-enhanced dynamic features in a 3D city model, which is enhanced to act as an energy system that allows the public to understand the energy consumptions and sources of the city. The presented solution should be considered as an open paradigm for representing complex geospatial 3D features associated with interactions and dynamic visualizations, rather than a concrete solution or pattern. Based on this paradigm, more advanced dynamic or interactive components can be added for better results. From a geo-visualization perspective, several types of dynamic features are presented and analysed as the result. Compared to

the 2D visualization, the 3D visualization is often more realistic-oriented by default, which to some degree limits the visualization approaches that represent thematic information; however, based on the case of developing solar collectors, we found out that a realistic depiction of changeable features not always works effectively, and sometimes even fails to convey correct information. We also found that free navigation isn't preferable because dynamic action in the model is better observed at close range and from certain angles, like a rendered still image. This was a first prototype and we learned a lot, which at the end is the most important part.

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